Dosimetric evaluation and comparison of different RF exposure apparatuses used in human volunteer studies

Boutry, C M ; Kuehn, S ; Achermann, P ; Romann, A ; Keshvari, J ; Kuster, N

Abstract: The aim of this study was to provide the information necessary to enable the comparison of exposure conditions in different human volunteer studies published by the research groups at the Universities of Turku, Swinburne, and Zurich. The latter applied a setup optimized for human volunteer studies in the context of risk assessment while the first two applied a modified commercial mobile phone for which detailed dosimetric data were lacking. While the Zurich Setup exposed the entire cortex of the target hemisphere, the other two setups resulted in only very localized exposure of the upper cheek, and concentrated on a limited area of the middle temporal gyrus just above the ear. The resulting peak spatial SAR averaged over 1 g of the cortex was 0.19 W/kg of the Swinburne Setup, and 0.31 W/kg for the Turku Setup, compared to 1 W/kg for the Zurich Setup. The average exposure of the thalamus was 5% and 9% of the Zurich Setup results for the Swinburne and Turku Setups, respectively. In general, the phone-based setup results in only reasonably defined exposures in a very limited area around the maximum exposure; the exposure of the rest of the cortex was low, and may vary greatly as a function of the setup, position, and local anatomy. The analysis confirms the need for a carefully designed exposure setup that exposes the relevant brain areas to a well-defined level in human volunteer studies, and shows that studies can only be properly compared and replicated if sufficiently detailed dosimetric information is available.

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Dosimetric Evaluation and Comparison of Different RF Exposure Apparatuses Used in Human Volunteer Studies

Clémentine M. Boutry,[1] Sven Kuehn,[1] Peter Achermann,[2] Albert Romann,[1] Jafar Keshvari,[3] and Niels Kuster[1]*

[1]*Foundation for Research on Information Technologies in Society, ETH Zurich, Switzerland*
[2]*Institute of Pharmacology and Toxicology, University of Zurich, Switzerland*
[3]*Nokia Research Center, Helsinki, Finland*

The aim of this study was to provide the information necessary to enable the comparison of exposure conditions in different human volunteer studies published by the research groups at the Universities of Turku, Swinburne, and Zurich. The latter applied a setup optimized for human volunteer studies in the context of risk assessment while the first two applied a modified commercial mobile phone for which detailed dosimetric data were lacking. While the Zurich Setup exposed the entire cortex of the target hemisphere, the other two setups resulted in only very localized exposure of the upper cheek, and concentrated on a limited area of the middle temporal gyrus just above the ear. The resulting peak spatial SAR averaged over 1 g of the cortex was 0.19 W/kg of the Swinburne Setup, and 0.31 W/kg for the Turku Setup, compared to 1 W/kg for the Zurich Setup. The average exposure of the thalamus was 5% and 9% of the Zurich Setup results for the Swinburne and Turku Setups, respectively. In general, the phone-based setup results in only reasonably defined exposures in a very limited area around the maximum exposure; the exposure of the rest of the cortex was low, and may vary greatly as a function of the setup, position, and local anatomy. The analysis confirms the need for a carefully designed exposure setup that exposes the relevant brain areas to a well-defined level in human volunteer studies, and shows that studies can only be properly compared and replicated if sufficiently detailed dosimetric information is available. Bioelectromagnetics 29:11–19, 2008.

Key words: dosimetry; cellular phones; electromagnetic fields (EMF); volunteer studies; electroencephalogram; cognitive function; sleep

INTRODUCTION

Experimental exposures of human volunteers are well-suited to evaluate possible acute effects of mobile communications in the context of health risk assessments. Today the reported outcomes of human volunteer studies addressing effects on the human central nervous system (CNS) are one of the most controversially discussed areas in electromagnetic (EM) research [Hossmann and Hermann, 2003]. Potential reasons might include poorly defined exposure and the lack of detailed dosimetric data, thus hindering interpretation of effects or lack of effects as well as preventing the possibility of replicating a study.

In the past, the selected exposure source for human volunteer studies ranged from placing an active mobile phone next to a bed [Mann and Roschke, 1996], resulting in poorly defined low-level exposure, to very controlled exposures explicitly designed for health risk assessment studies [Huber et al., 2000, 2003].

Most research groups have selected a modified commercial or generic mobile phone to provide a cost-efficient exposure system (e.g., Nokia 5110 [Croft et al., 2002], Nokia 3210 [Lee et al., 2003], Nokia 3110 [Preece et al., 2005], see also Cook et al. [2006]). It

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*Correspondence to: Niels Kuster, IT'IS Foundation, Zeughausstrasse 43, CH-8004 Zurich, Switzerland.
E-mail: kuster@itis.ethz.ch

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is not known to many researchers that each mobile phone has a unique footprint of exposure that significantly differs from phone to phone. Thus, each phone results in a greatly different field strength distribution induced in the brain tissues that is not only a function of this footprint, but also of the position of the mobile phone with respect to the head. As demonstrated in Kuster et al. [2004], the peak spatial SAR within the cortex can vary by more than a factor of 20 from phone to phone and the exposure of sub-cortical-regions by more than a hundred. Therefore, usage of actual phones in human studies leads to an arbitrary exposure not representing the exposure of general phone usage when considering the exposure of specific neural cell populations. This has led to the conclusion that modified and generic mobile phones are a poor choice for investigating the effects of mobile phone exposure on CNS functions.

For most of the studies with information on SAR values, the dosimetry provided was limited to the peak spatial SAR determined with the procedures defined for testing compliance with safety guidelines [IEEE, 2003; IEC, 2007]. The procedure had been optimized to provide a conservative estimate of the maximum exposure occurring in any tissue of more than 90% of the users. However, it does not necessarily reflect the location of the peak correctly. Thus, the peak spatial SAR as developed for compliance testing is a very poor and misleading metric to describe exposure, since it correlates poorly to the exposed brain regions and does not provide any information about the location of maximum absorption nor about the shape of the footprint of a phone.

To interpret results and in particular conflicting findings, it is important that the appropriate dosimetric information is available. The objective of this report is to provide detailed dosimetry for the exposure setups based on a modified commercial NOKIA 6110 mobile phone used in several studies at the University of Turku (*Turku Setup*) [Haarala et al., 2003, 2004, 2005, 2006] and at Swinburne University (*Swinburne Setup*) [Loughran et al., 2005] and compare the data with the setup applied in the studies at the University of Zurich (*Zurich Setup*) [Huber et al., 2000, 2002, 2003, 2005; Regel et al., 2006, 2007].

Cooperation with the respective research groups enabled this post-experiment dosimetric analysis. We were permitted access to the mobile phones actually used as well as given sufficient information about the device position and its variation with respect to the head. An overview of the studies performed with the respective setups is summarized in Table 1.

MATERIALS AND METHODS

The detailed dosimetric analysis is based on numerical simulations that have been extensively validated by measurements with phantoms.

The simulations were performed using the finite-difference time-domain (FDTD) based platform SEMCAD X (SPEAG, Zurich, Switzerland). The human numerical model employed for the detailed dosimetry is currently the most detailed inhomogeneous model for which different sub-brain regions have been distinguished. The model is based on a data set of the head of a healthy female subject (aged 40 years), consisting of 121 magnetic resonance images (MRI), with a slice separation of 1 mm in the ear region and 3 mm for the rest of the head [Burkhardt and Kuster, 2000]. During the MRI scans, the pinna of the ear was

TABLE 1. Comparison of Exposure Apparatuses Used by the Three Research Groups

	Turku Setup [Haarala et al., 2003, 2004, 2005, 2006]	Swinburne Setup [Loughran et al., 2005]	Zurich Setup [Huber et al., 2000, 2002, 2003, 2005; Regel et al., 2006, 2007]
Study type	Human studies on cognitive performance	Human sleep EEG study	Human sleep/wake EEG studies, cognitive performance, brain physiology
Exposure setup	Nokia 6110 mobile phone	Nokia 6110 mobile phone	Planar patch antenna
Side of exposure	Left	Right	Left or right in Huber et al. [2000, 2003] Left in Huber et al. [2002, 2005]; Regel et al. [2006, 2007]
Frequency	902 MHz	895 MHz	900 MHz
Modulation	GSM basic	GSM basic	GSM base-station-like or handset-like
Antenna input power	PCL[a] = 5	PCL[a] = 5	Set for psSAR10g[b] = 1W/kg in Huber et al. [2000, 2002, 2003, 2005]; Regel et al. [2007] Set for psSAR10g[b] = 0.2 and 5 W/kg in Regel et al. [2006]

[a]Power control level (PCL), corresponding to a nominal output power of 33dBm ±4 dB [ETSI-3GPP, 2005]. Note that for most phones the actual input power is towards the lower end of the accepted range.
[b]Peak spatial SAR averaged over any 10 g tissue (psSAR10g) in the shape of a cube assessed according to the procedure for compliance testing [IEEE, 2003; IEC, 2007]. The efficiency of the patch antenna setup was 0.54 W/kg (psSAR10g) per Watt antenna input power.

pressed with a flat piece of foam against the head as occurs during usage of a mobile phone. The dielectric parameters of the 23 discriminated tissues used to estimate the SAR distribution in the brain are provided in Table 2.

Within the brain, gray and white matter, cerebrospinal fluid (CSF), midbrain, and thalamus were distinguished. The latter was motivated by the hypothesis that sub-cortical regions (including the thalamus) may contain the structures most sensitive to RF EMF. Because the EEG effect did not depend on the side of exposure [Huber et al., 2000, 2003] it was hypothesized that bilateral cortical projections from sub-cortical structures may explain the absence of a hemispheric asymmetry. For validation, the same phantoms as defined for compliance testing [IEC, 2007] were used, that is, a flat phantom, and the specific anthropomorphic mannequin (SAM).

Measurements were conducted with the near-field scanning systems DASY4, for assessment based on SAM, and the immediate scanner iSAR (SPEAG, Switzerland), to provide data for the flat phantom configuration as defined in IEC [2007]. The iSAR software was utilized to quantitatively compare absorption patterns.

TABLE 2. Dielectric Parameters of the Tissue Types Discriminated in the Human Head Model (Relative Permittivity ε_r and Conductivity σ at 900 MHz) [Gabriel, 1996]

Tissue type	ε_r	σ (S/m)
Brain (gray matter)	20.8	0.34
Brain (white matter)	52.7	0.94
Brain (gray matter)	38.9	0.59
Cerebellum	49.4	1.26
Cerebro-spinal fluid	68.6	2.41
Cornea	55.2	1.39
Ear (avg. skin and cartilage)	42.0	0.82
Fat	5.5	0.05
Lens	41.2	0.64
Lower jaw	20.8	0.34
Mastoid bone	20.8	0.34
Midbrain	52.7	0.94
Muscle	55.0	0.94
Nasal cavity	1.0	0.00
Pterygiod muscle	55.0	0.94
Skin	41.4	0.87
Skull	16.6	0.24
Spinal cord	52.7	0.94
Spine	20.8	0.34
Thalamus	52.7	0.94
Tongue	55.3	0.94
Upper jaw	20.8	0.34
Lateral ventricles	68.6	2.41
Vitreous humor	68.9	1.64

EXPERIMENTAL AND NUMERICAL PHONE MODELS

Experimental Mobile Phones

Three NOKIA 6110 mobile phones were employed in this study. The two original mobile phones used at the Universities of Turku and Swinburne were made available for experimental evaluations, and a third mobile phone was disassembled to support the construction of the numerical model derived from the CAD data set (Fig. 1).

Numerical Phone

Mechanical CAD data were provided by NOKIA. Since the mobile phone was from the late 1990s, the data set was not as complete as for current models; important parts such as the antenna were missing, and had to be reconstructed from scratch. Furthermore, the dielectric parameters of the various parts were also unavailable. All metallic parts were modeled as perfect electric conductors (PEC), that is, antenna, shields, and connectors. The same dielectric parameters as applied in Chavannes et al. [2003] were used (see Table 3). The printed circuit board (PCB) originally consisted of just one single PEC block; this was modified to represent internal losses. One dielectric layer was consequently embedded into two PEC ground layers, connected using 50 interconnecting vias uniformly distributed over the entire PCB area [Chavannes et al., 2003]. The source was modeled as a discrete voltage edge source, placed between the PCB ground layer and the isolated PEC region connected to the antenna (air gap of 4 mm, see Fig. 2). Non-uniform grids were applied ranging from 0.2 mm (antenna) to 2 mm (human head numerical model) and 3.6 mm (SAM phantom).

Validation and Uncertainty Assessment of the Numerical Model

The numerical phone model was validated only with respect to its dosimetry and did not include a complete assessment of dosimetry including far-field as conducted in Chavannes et al. [2003], since the over-the-air performance of the mobile phone was not relevant in the present context.

The absorption patterns between simulations and measurements were compared for different load conditions, that is, for distances from the flat phantom of 3, 6, 10, 20, and 40 mm. The quality of the pattern match was compared by interpolating, scaling, and registering the two SAR patterns, and employing a variation of the gamma method [Low et al., 1998; Low and Dempsey, 2003]. This algorithm searches for corresponding points in the two distributions using

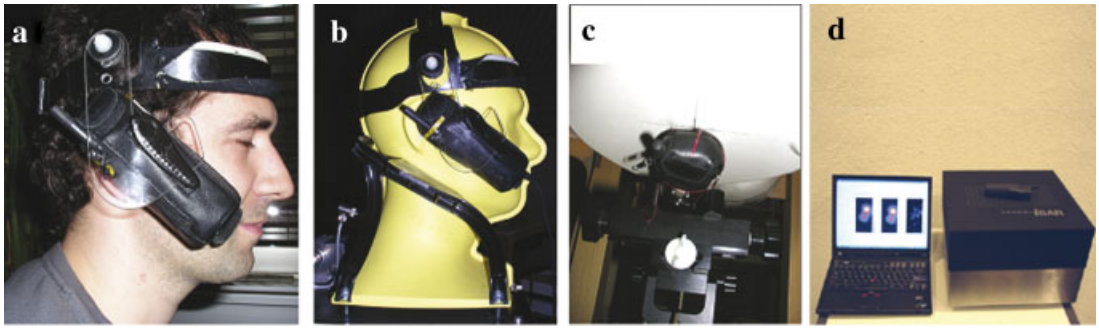

Fig. 1. **a**: *Swinburne Setup*. The Nokia 6110 mobile phone was placed in a case made of leather and vinyl and mounted at the subjects head with an adjustable rubber head cap. The same setup was mounted for dosimetric evaluation on the (**b**) SAM phantom and (**c**) flat phantom. **d**: The iSAR system was used to measure the Nokia 6110 mobile phone footprint and validate the mobile phone numerical model. [The color figure for this article is available online at www.interscience.wiley.com.]

two input parameters: the spatial tolerance (tol_s), which specifies how strongly the distance between the corresponding points is weighted, and a value tolerance (tol_f) that specifies how strongly the deviations among measured SAR are weighted. The normalized difference to every point in the numerical distribution was compared using the following equation:

$$\sqrt{\left(\frac{\mathrm{d}s}{\mathrm{tol}_s}\right)^2+\left(\frac{\mathrm{d}f}{\mathrm{tol}_f}\right)^2} \qquad (1)$$

with ds the distance between the two points and df the SAR difference between the two points. Both spatial distances ds and SAR differences df increase the normalized difference. The two points with the smallest normalized difference are considered corresponding points in the two measurements. This provides a quantitative comparison of the patterns. The percentage of points within 10% when weighted with the peak was always above 90%, demonstrating that the developed numerical phone well represented the exposure of the two mobile phones used in the setups.

The antenna input power is not known for all commercial phones and may vary within a rather large range. In the case of the *Turku Setup*, the antenna input power at power control level 5 [ETSI-3GPP, 2005] resulting in the equivalent SAR pattern was determined based on the flat phantom data. In the case of the *Swinburne Setup* it was derived from the measurements with the SAM phantom for different phone positions using a least square fit.

The uncertainty of the numerical phone model was evaluated following the concept of NIST TN1297 Taylor and Kuyatt [1994]. The parameters considered were the uncertainty of (1) the dosimetric footprint, (2) antenna input power, (3) dielectric parameters (assessed by varying the relative permittivity and conductivity of the dielectric parts of the phone by $\pm 10\%$), (4) model discretization (estimated by comparing voxel sizes of $0.16 \times 0.16 \times 0.16$ mm^3, $0.22 \times 0.22 \times 0.22$ mm^3, and $0.3 \times 0.3 \times 0.3$ mm^3), (5) the DASY4 system uncertainty budget for dosimetric assessments [SPEAG, 2004], calculated according to IEC [2007]. The combined standard uncertainty ($k = 1$ or coverage of 66%) of the numerical phone model was found to be 13.7% for both 1 g spatial averaged peak SAR and average SAR.

TABLE 3. The Main Dielectric Parts of the Phone CAD Data Set and the Corresponding Dielectric Parameters (Relative Permittivity ε_r and Conductivity σ at 900 MHz) [Chavannes et al., 2003]

Part	ε_r	σ (S/m)
Antenna cover	3.5	0.02
Printed circuit board (PCB) dielectric	4.5	0.07
Liquid crystal display (LCD) glass	4.5	0.01
Housing	3.5	0.02
Keypad/buttons	3.5	0.02

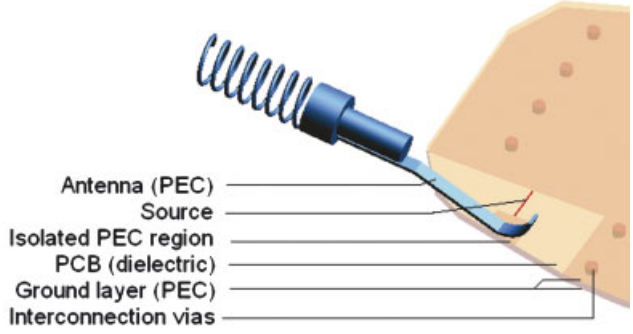

Fig. 2. Mobile phone numerical model: The excitation of the antenna-PCB structure in the modified source region. [The color figure for this article is available online at www.interscience.wiley.com.]

DOSIMETRIC RESULTS

In both the *Turku* and *Swinburne Setups*, the mobile phone was placed in a case made of leather and vinyl and mounted at the subject's head with an adjustable rubber head cap. The virtual speaker of the mobile phone (removed for the study to avoid acoustic interferences) was located over the auditory canal, and the microphone was aligned toward the corner of the mouth. The mobile phone was mounted on the left side of the head in the *Turku Setup*, whereas in the *Swinburne Setup* it was located on the right side. The position of the mobile phone was characterized by the distance of the base of the antenna to the skull, that is, 33.7 ± 2.6 mm (SD) for the *Turku Setup* and 68.4 ± 2.5 mm (SD) for the *Swinburne Setup*.

The dosimetry was conducted following the guidelines of Kuster et al. [2004] using the same parameters as reported in Huber et al. [2003]. The voxel size was $2 \times 2 \times 2$ mm^3 for the head and $0.22 \times 0.22 \times 0.22$ mm^3 for the phone antenna, for a total number of approximately 13 million voxels. The tissue models and SAR distributions for the three setups are shown in Figure 3. The 1 g averaged peak spatial SAR

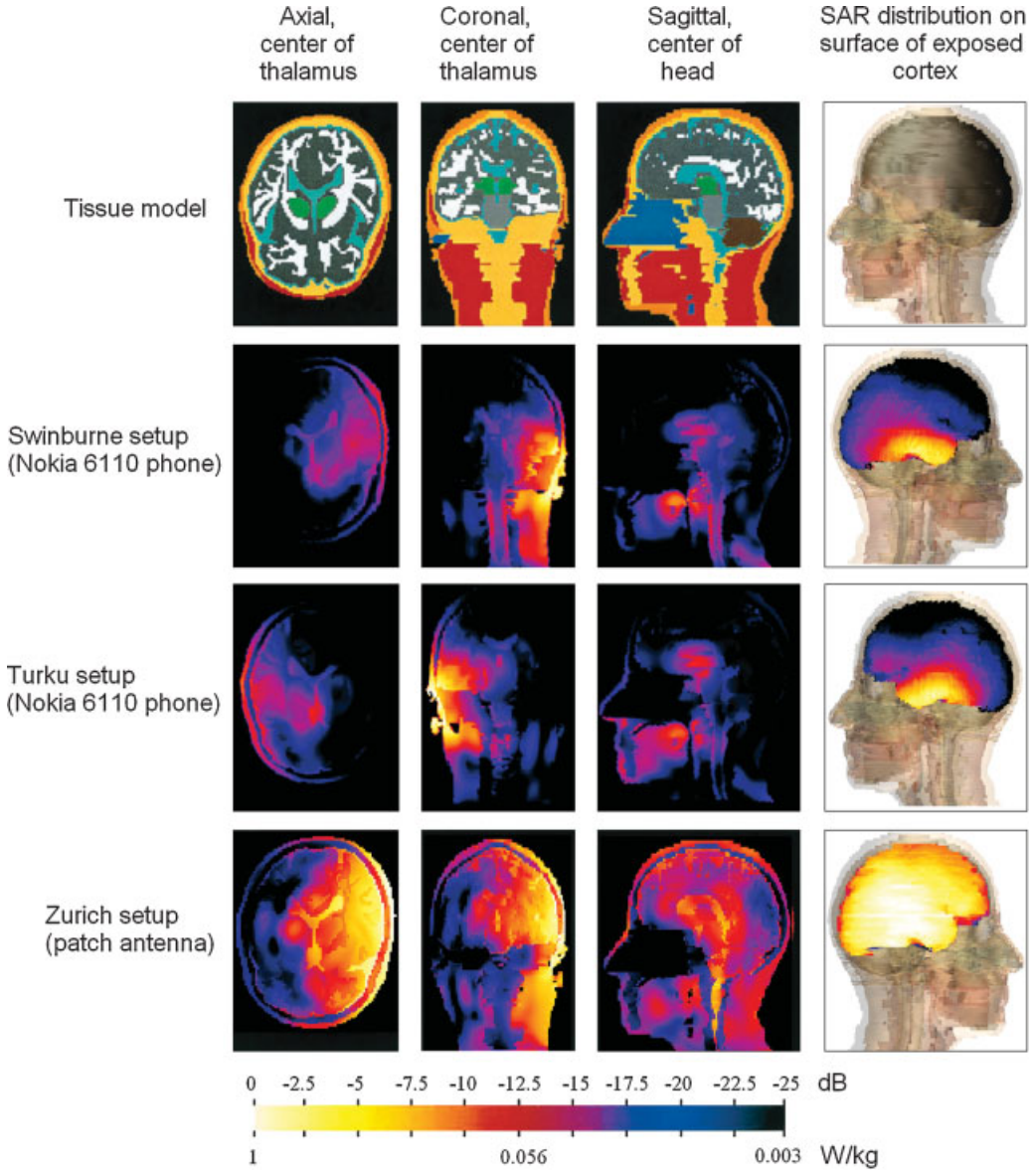

Fig. 3. Estimated distribution of the specific absorption rate (SAR) for the tissue model shown in the top row. The second, third and fourth rows give the SAR distributions for *Swinburne*, *Turku* and *Zurich Setups*.

and the averaged SAR for the different tissues are summarized in Table 4 and compared to the corresponding values of the patch antenna setup as reported in Huber et al. [2003].

The *Zurich Setup* exposed the entire cortex of the target hemisphere rather uniformly with a 1 g averaged peak spatial SAR of 1020 mW/kg. The other two setups resulted in a very localized exposure of the upper cheek, and the inner ear, and concentrated on a limited area of the mid-temporal gyrus just above the ear. The resulting peak spatial SAR averaged over 1 g of the exposed hemisphere of the cortex was 0.19 W/kg for the *Swinburne Setup* and 0.31 W/kg for the *Turku Setup*. The average exposure of the thalamus was 5% and 9% of the *Zurich Setup* for the *Swinburne* and *Turku Setups*, respectively. The exposures of the cortex other than around the peak location for the phone setups are very low compared to the *Zurich Setup* (<1%, Fig. 3). The uncertainty analysis included (1) the dielectric parameters of the head, assessed by varying the relative permittivity and conductivity of the dielectric parts of the head numerical model by ±10%; (2) the discretization of the head, estimated by comparing voxel sizes of $1.6 \times 1.6 \times 1.6$ mm^3, $2 \times 2 \times 2$ mm^3, and $3.9 \times 3.9 \times 3.9$ mm^3; (3) the segmentation of the head; (4) the numerical phone model uncertainty as assessed according to the previous section. The segmentation uncertainty of the head anatomy was estimated based on the differences between left and right sides for the same antenna exposure.

The higher combined standard uncertainty for the thalamus compared to the other tissues evaluated in Table 4 can be explained by higher dependence on the dielectric parameters. The main parameters for variations in the exposure were (1) different head size, assessed by scaling the head model by ±10%, which was found to be the maximum variation in head size measured by Tisserand et al. [2001]; (2) changes in phone position relative to the head. Since the head anatomy may be one of the key parameters of variations, improved values could be obtained by using several head phantoms.

The main contribution to the total variability was the variation of the head anatomy and head size. It was observed that the local SAR was very sensitive to a variation of the phone position relative to the head. The magnitude of the peak spatial SAR also varied with the phone position. In contrast, the average SAR varied more when varying the head size.

DISCUSSION AND CONCLUSIONS

The dosimetry revealed clear differences between the two setups based on the NOKIA 6110 and the *Zurich Setup*. The *Zurich Setup* was designed to mimic the exposure of a handset covering many possible footprints and holding positions as well as to minimize the variability of the exposure from subject to subject. Thus, the entire cortex of the target hemisphere was exposed to a similar or slightly higher degree as may occur during typical mobile phone conversations, while the other two setups resulted in very localized exposure that is realistic only for a limited subset of mobile phones in the touch position.

The exposures of the three setups deviate by a factor of 3–5 for the regions of the middle temporal gyrus, the thalamus, and the inner ear, that is, the spatial peak SAR of the cortex in the *Turku Setup* and the *Swinburne Setup* correspond to approximately 31% and 19% of the levels of the Zurich studies, respectively. The exposure of the deeper brain structures is lower by more than a factor of 10. The remaining cortical areas are generally below exposure levels of the *Zurich Setup* by a factor of 100.

Loughran et al. [2005] reported effects on the sleep EEG similar to those observed in Zurich [Huber et al., 2002]. A possible interpretation could be that the low and spatially concentrated exposure levels might be sufficient to induce an effect. However, this is not in line with a recent dose-response study [Regel et al., 2006] where low exposure to a spatial peak SAR of 0.2 W/kg resulted in a non-significant effect. Factors such as sample size and age distribution of the participants are obviously of equal importance as the exposure conditions when comparing different studies. Furthermore, inconsistencies in results may possibly be related to the spectral content of the applied RF EMF. We recently found that pulse modulation of the RF EMF is necessary to induce changes in the EEG in waking and sleep [Huber et al., 2000; Regel et al., 2007]. The changes in non-REM sleep as induced by a 'base-station-like' RF EMF [Borbély et al., 1999; Huber et al., 2000] and a 'handset-like' RF EMF [Huber et al., 2002] were not identical and compared with the 'handset-like' exposure, 'base-station-like' exposure had only limited effects on regional cerebral blood flow [Huber et al., 2005].

Human volunteer studies investigating effects on CNS functions in the context of risk assessments should aim to determine whether the investigated endpoint may occur in daily life. It must be assumed that possible effects depend on the exposure level of specific functional brain regions and therefore relevant brain structures have to be exposed to a sufficient degree. This study revealed that this cannot be achieved with one particular modified or generic mobile phone, and therefore they cannot be used to demonstrate the absence of effects on the CNS due to mobile phone

TABLE 4. Specific Absorption Rate (SAR) of Head Tissues for the *Swinburne* and *Turku Setups* (Nokia 6110 Mobile Phone Placed on the Right and Left Sides of the Head), and for the *Zurich Setup* (Patch Antenna), With Variations and Uncertainties

	Both hemispheres				Right hemisphere				Left hemisphere				Variation[a]		Uncertainty[a]	
	1 g[b] (mW/kg)	Avg.[c] (mW/kg)	SD[d] (mW/kg)	Loss.[e] (mW)	1 g[b] (mW/kg)	Avg.[c] (mW/kg)	SD[d] (mW/kg)	Loss.[e] (mW)	1 g[b] (mW/kg)	Avg.[c] (mW/kg)	SD[d] (mW/kg)	Loss.[e] (mW)	1 g[b] %	avg.[c] %	1 g[b] %	Avg.[c] %
Swinburne Setup																
Gray matter	187	7.09	18.5	6.27	187	13.2	24.8	5.96	6.91	0.91	1.01	0.39	20	33	23	23
White matter	125	6.18	16.6	2.28	125	13.3	23.3	2.21	3.35	0.50	0.47	0.10	20	31	23	23
Gray & white mat.	172	6.82	18.0	8.55	172	13.2	24.4	8.18	6.89	0.78	0.89	0.49	20	32	23	23
Thalamus	10.8	5.93	2.94	0.071	10.8	8.32	2.31	0.050	6.30	3.84	1.67	0.023	46	55	30	31
Brain avg. no v. l.[f]	247	8.06	23.7	13.4	247	15.3	32.8	12.5	29.0	1.30	2.57	1.09	20	34	23	23
Brain avg.	247	8.08	23.7	13.4	247	15.3	32.8	12.5	29.0	1.30	2.57	1.10	20	34	23	23
Total head	901	19.7	69.7	91.2	901	37.7	95.7	88.3	81.6	1.79	4.56	4.10	18	26	23	22
Turku Setup																
Gray matter	311	10.5	30.9	9.33	14.1	1.28	1.55	0.60	311	20.9	42.7	8.73	20	32	22	23
White matter	173	9.41	25.0	3.46	4.59	0.75	0.66	0.13	173	16.6	32.1	3.34	21	31	23	23
Gray & white mat.	294	10.2	29.3	12.8	14.0	1.14	1.39	0.73	294	19.5	39.6	12.1	20	32	22	23
Thalamus	23.9	11.1	6.63	0.13	11.4	6.70	3.10	0.040	23.9	15.5	6.25	0.093	35	47	27	28
Brain avg. no v. l.[f]	415	11.2	35.5	18.5	28.0	1.72	2.97	1.46	415	20.9	48.7	17.1	19	33	22	23
Brain avg.	415	11.2	35.5	18.6	28.0	1.72	2.97	1.46	415	21.0	48.7	17.1	19	33	22	23
Total head	891	20.1	67.3	93.0	78.2	2.40	4.99	5.70	891	38.5	92.5	87.3	20	26	22	22
Zurich Setup[g]																
Gray matter	1020	150	180	135	1020	250	190	121	150	30.0	30.0	13.4	19	19	15	14
White matter	610	100	120	37.7	610	200	130	34.0	80.0	20.0	10.0	3.85	17	17	14	14
Gray & white mat.	970	130	160	173	970	240	180	155	140	30.0	20.0	17.2	19	19	14	14
Thalamus	160	120	30.0	1.49	160	130	20.0	0.86	130	100	30.0	0.67	29	29	17	22
Brain avg. no v. l.[f]	970	140	160	272	970	240	180	240	150	30.0	30.0	32.9	17	17	15	14
Brain avg.	1550	160	220	271	1550	270	260	239	330	40.0	50.0	32.9	17	17	15	14
Total head	1881	134	226	618	1881	230	279	552	239	29.6	37.2	65.7	17	17	15	14

The brain avg. values included brain gray matter, brain white matter, cerebellum, Midbrain, thalamus, cerebro-spinal fluid (CSF) and ventriculus lateralis.
The Total head includes all the 23 head tissues in Table 2.
The SAR values include the normalization factor calculated for the *Swinburne* and *Turku Setups*.
[a]Variation and uncertainty for $k = 1$ or coverage factor of 66%.
[b]Peak spatial SAR averaged over a cube of 1 g tissue.
[c]Tissue averaged SAR.
[d]Standard deviation of the averaged SAR.
[e]Total power losses.
[f]Brain average without ventriculus lateralis.
[g]Results from Huber et al. [2003].

exposures. The results of our dosimetric assessment of the different setups demonstrate that a well-designed exposure setup or several different exposures by mobile phones that exposes all relevant brain areas have to be used in future studies. Furthermore, a detailed dosimetry as defined in Kuster et al. [2004] has to be performed prior to performing laborious studies. Inadequate exposure may lead to a waste of resources. Without detailed dosimetry, different studies cannot be properly compared even for apparently similar exposure conditions (e.g., similar peak SAR), since the differences in the exposed tissue might be very large.

This has led to the conclusion that modified and generic mobile phones are a poor choice for investigating the effects of mobile phone exposure on CNS functions. On the other hand it must be noted that the exposure pattern of the Zurich setup does not correspond to a single exposure but rather a superposition of various patterns and positions.

Although the appropriate exposure conditions including detailed dosimetry can be regarded as a fundamental key parameter, many other factors (e.g., exposure duration, time of the exposure during the day, sample size, blinding, age, and gender of the subjects, etc.) must be carefully selected and reported to enable the comparison of studies.

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